Advances in Additive Manufacturing of Materials: Current status and emerging opportunities

Prof. Bikramjit Basu

Materials Research Center, Indian Institute of Science, Bangalore

Lecture 44

let me continue our discussion on the 3D printing of ceramic dental implants. What we have learned from the last lecture is that what is dental implants and then what are the different sizes, what is this different bone density that clinicians encounter in human patients depending on the different spatial location in the upper and lower jawbone. Then how this dental implant surgery takes place, what are the different components of the dental implant and then essentially we looked at that how this implants can be manufactured using conventional CNC manufacturing or additive manufacturing and also what are the surface treatment techniques that are being used for metallic dental implants. since this particular case study is more related to the ceramic dental implants, let me start this lecture with the surface modification strategy that can be adopted for ceramic dental implants. I would like to remind you that ceramic dental implants particularly is a single piece implants unlike metallic dental implants and that was one of the major differences between the use of ceramic and the metallic dental implants. Metallic dental implants can be used in in the 2 piece or 3 piece dental implants whereas ceramic dental implants is always manufactured in single piece.

this is the external threaded implants as you can see and it has a very blunt kind of a shape. in the machine surface you can see lot of these groups right, these are machining induced groups in the scanning electron microscopy images. Once you do acid etching, then you can see more like dimple type of features. You can do sandblasting like the way you have seen for the metal dental implants and then you can see there is a large groups.

large groups you can see because of dental implants. And one is that sand blasted and acid etched typically ceramic implants are manufactured from zirconia based materials. people have used 3 mole percent yttria stabilized zirconia, 3y means 3 mole percent yttria stabilized zirconia. It is a tetragonal form. It has good strength properties.

People have also used ZTA zirconia toughened alumina or ATZ kind of materials, ATZ is like alumina toughened zirconia or ZTA is a zirconia toughened alumina. instead of acid sandblasted and acid etched essentially you can also use in case of zirconia based materials as I showed you in the last slide that is the sandblasting and acid etching. this sand instead of alumina one can also use zirconia particles. you can bombard the zirconia implant surfaces by zirconia particles and then subsequently you can do acid edging. Then coatings, one can use the silica coatings or magnesium coatings or graphene coatings, graphene and dopamine coatings, these are like different coatings which you can put it on the dental implants.

as I said that implant when you design this external thread, one of the major thing that one has to carefully consider is this primary and secondary stability of the implants. primary stability of the implants that essentially means that immediately after the implantation what is the implant stability quotients and this is typically measured by RFA, radio frequency analyzer or the final torque that you essentially need to firmly place the implant at the implantation site. this is the gap at this bone implant interface, this wide gaps you can notice, this is the cortical

bone and this is the cancellous bone. Cortical bone is the cover one, cancellous bone is this one. After the osseointegration, you expect the new bone formation essentially covers this .

So, one is the case for primary stability, once across integration this is the case for this new bone that I have mentioned just now. new bone means the bone this morphology of this particular new bone would be different from the existing bone structure that you have at places remote from site of implantation. essentially factors which decide primary stability is the bone density like as I said D1, D2, D3, D4, what is the drilling protocol you have used, what is the implant geometry and what is the insertion procedure. Factors which determine secondary stability is the new bone formation and loading. Loading means when you are essentially load the prosthesis.

Anytime I use the term prosthesis means it is crown. Anytime I use the term loading in the context of dental implantation means you are essentially load the crown at the final stage after the placement of the crown. factors which affect primary stability just to substantiate more is certainly gender, male versus female, age is equally important, then implant size and shape, then bone quality and quantity, how much is a bone and also surgical procedure how it has been used. as I mentioned just few minutes ago, Resonance Frequency Analyzer, RFA has been used very extensively in the high quality dental implantology procedures by measuring implant stability quotient. this is nothing but ISQ.

this ISQ values if it is between 65 to 70, this is a very good primary stability of the implants. implant at risk whether the ISQ value is less than 60 , if implant will have medium stability, it is below 70, 70 and above is a good ISQ of the implants which will definitely have good primary stability. this is like more quantitative way of measuring implant stability rather than simply by eye estimate or clinical evidences and so on. you can see this is the insertion removal torque. Now, you can see in a patient's, you can see in the saw bone that is the structure synthetic bone that these implants are getting drilled and then you can see the torque values that is the 40 Newton centimeter torque values that needs to be applied.

you can see this implant is being placed. you can see that what is the relevance of the insertion torque study analysis in the realm of actually clinical dental implantology. you can see that clinician is placing the implants by very carefully applying the torque as the implant is getting deeper and deeper into the jawbone, into the cavity being created in the lower jawbone, what you do in the preclinical performance analysis by measuring the insertion torque, you can see what is the relevance in the actual clinics. Another performance limitation test is typically is a dynamic fatigue test. It has to be done according to the ISO 14801 guidelines in 2016.

this dynamic fatigue test you can see this is the cyclic loading is being applied. where the implants is essentially held. at 30 degree that is kind of angular positioning and then it has to be inserted at the normal bone level like 3 millimeter. 3 millimeter will be outside this particular block and then rest of the implants will be placed below the bone level and if you see this particular video, This region you can see the video, it is a small amplitude around 2 Hertz, that frequency is being given. It has to sustain 2 million cycles, it is like 2 Hertz frequency.

It is a NaCl containing saline solution, this is in the saline medium. and you can see this angle is almost like 30 degree. You can see this is that actual movie. Because of the very low frequency, you are not able to see this movement very very clearly. But it is extremely slow frequency testing the dental implant.

key applications of this kind of Chewing simulator that also can be used , here you can see this is the crown, simulation of occlusal spleens and fracture resistance of the crown. Then you can see determination of wear

resistance of the composites, crowns, bridges and implants and bruxism to test occlusal splints. what are the clinical outcome that needs to be measured once this implant goes through all the performance limiting test, finally goes to the ethical approval for the clinical studies. For the primary outcomes, these are like implant survival and success rate, mean bone level as evaluated using radiographs or CBCT images. cone beam computed tomography, secondary outcomes like mean osseointegration period, dental plaque assessment, gingival bleeding assessment, periodontal pocket depth.

these are like osseointegration evaluation. So, this is like gingival bleeding assessment. These are like how 0, 1, 2, 3, 4 like no inflammation to severe inflammation that can be assessed. Plaque assessment also can be very low plaque to very severe plaque assessment. these are like qualitative grading 0 to 5.

Periodontal pocket depth. what is the pocket depth that one can measure like 1 to 3 millimeter to 7 to 12 millimeter periodontal pocket depth and also integration evaluation. clinical evidence of successful osseointegration, implant should not be mobile when tested clinically, site should be asymptomatic like absence of any persistent signs or symptoms such as pain infections, stable crystal bone defects, bone levels like less than 0.2 millimeter, radiographic evidence of increasing mineralization of the newly formed bone at the implant site, healthy soft tissue and absence of peri-implant radiolucency. these are like clinical evidences for successful osseointegration.

Now, these are like public studies, few clinical reports. this green line essentially shows where the bone should be and red essentially shows that there is a bone loss. this bone loss is certainly not clinically appreciated. Now, there is also ailing implants like you can see that there is a soft tissue surrounding the implants, around the implants. And what is the perfect implantation? This is your natural tooth.

And this is that implants without crown, now this crown can be placed to have this one. if you see this osseointegration of this natural tooth and osseointegration of the synthetic or as manufactured implants, these are like comparable. Now zirconia single piece implants, now this is that what when we have started the ceramic dental implants we have used 3 mole percentage to stabilize zirconia. As I mentioned this is 3YSZ. One of the major thing that we are trying to innovate is the CAD models, what is the design concepts like length is 19.

75 millimeter, this platform diameter is that 5.45 diameter. We have the different kind of screw threads geometry. Then, subsequently we have used stereolithography based 3D printing with laser spot diameter 60 micron, layer thickness is 25 micron. Then after this 3D printing is over and then what is stereolithography based ceramic printing that I am going to explain to you soon.

This is that as machined implant prototypes that has been manufactured and surface roughness as indicated by surface roughness values around 0.2 micron. it is much much less than 1 micron that is what clinically acceptable. And these are 3D printed single piece dental implants and then you can see these are V-threads, these are buttress threads and there is also V-threads. How ceramic printing is commercially practiced or practiced as a technology? You have the CAD file, stereolithography file.

Then you use these ceramic powders which is loaded to a photocross linkable binder and that undergoes polymerization technology when they are exposed to laser beam or when they will undergo lasing action. Printing is done. After the printing layer by layer, printing and again cleaning and debinding and sintering, then you get this end-reach part. this is essentially courtesy to 3D Ceram Sinto. That is a French company but one Japanese

company Sinto has taken over and then now it is known as 3D Serum Sinto.

if you look at this video, you will see that how ceramic printing actually takes place in practice. sereolithography SLA essentially uses top-down lasing action. which allows printing of complex design parts from a ceramic slurry loaded with photosensitive resin. So, essentially this photosensitive resin formulation is important and this photosensitive resin will have ceramic particles like 3 mole percent, yttria stabilized, zirconia and so on. So, at the end of the 3D printing experiments what you see these are like dental implants.

This multiple dental implants can be manufactured in a single shot, okay. And these dental implants are made up of the itrastabilized zirconia or it can be zirconia toughened alumina. But for any time you change the ceramic material, your binder formulation also will be different. And therefore, you have to also adjust that you know that other 3D printing related parameters. the quality of the 3D printed implants is always investigated using microcomputed tomography.

Although it has been introduced to you earlier, but let me go through this microcomputed tomography. In Indian Institute of science, we always use X-radia. this is the X ray microscope, you have X-ray source here and then then you have also sample holder and detector. sample holder is placed where you can see test specimen and then you have a detector. if you look at this particular video, the source generates the X-ray beam.

then which passes through the samples and when sample is being rotated around 360 degree very slowly. The sample absorbs X-rays and then X-ray projection is captured by the camera and a series of single 2D orthoslices are being acquired and these 2D orthoslices are then reconstructed to provide a 3D volume rendered images. This is the case for the fish shears structure and data must be converted to a usable format that is about it. and this also this computational reconstruction converts the projections into a tomogram. This data can be visualized and further analyzed using this Avijo software for example.

is non-destructive, it conducts scans at room temperature and atmospheric pressure now I will show you some examples of the micro-CT images of the square V-threaded dental implants. This is the software interface for controlling scanning parameters in micro-CT and you can see that what are the scanning parameters that were used in this particular micro-CT analysis. you have a segmented micro-CT data, this is the front view. And then you can see that when you get this micro CT, how these particular ceramic implants, they are being analyzed and you can see all different views as these implants are being segmented and then it is scanned in the micro CT.

And this is the respective CAD model. In the CAD model also if you rotate, then you can see the same thing and video of the scan sample means this is as 3D printed ceramic implant. you can visualize that how CAD model actually, how these micro CT scanned 3D printed images correspond with the CAD model at different orientation. what is the voltage that is typically used? 120 kilo volt, this is a large voltage in the micro CT that were used. Power is 10 watt, exposure time is 3 seconds, objective 0.

39x and source filter is air. this is how these samples are being placed inside the micro CT sample holder. Now measurements from the micro CT, we are interested to see that whether these materials, whether 3D printed implants has any porosity, but we could not find any porosity within the detection limit of the micro CT when we investigated several of the 2D ortho slices. One of the main thing for the 3D printing is to see that whether this dimensional tolerance can be maintained at different locations. for example, if you have the square threads and then we have found out that what is the design tolerance which is within 1.

23 percent, V square depth is 0.57, V thread depth is 1.02, pitch is 0.38, very good, face angle is 0.36. these are like measurements from ortho slices performed in a Avizo analysis.

With this, I conclude these two lectures on the ceramic dental implants and I am sure that you have learned about the various aspects of dental implants like what are the clinical treatment procedure and these different classifications of dental implants, conventional and additive manufacturing dental implants, different surface treatments, performance limiting properties, what are the pre-clinical performances like insertion torche study, fatigue study and so on. and pre-clinical and clinical case studies and as well as additive manufacturing of ceramic dental implants particularly their quality of how that can be determined using micro CT in terms of the dimensional tolerance, in terms of the whether there is any porosity in the structures and then also what is the design tolerance of this 3D printed ceramic dental implants. Thank you. you